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PROCEEDINGS

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AIRCRAFT DESIGN AS RELATED TO AIRPORT STANDARDS

By Milton W. Arnold

AIR TRANSPORT DIVISION

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AMERICAN SOCIETY OF CIVIL ENGINEERS
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PAPERS

AIRCRAFT DESIGN AS RELATED TO AIRPORT STANDARDS

By Milton W. Arnold[1]

Synopsis

The point in aviation has been reached at which a much closer correlation must be sought between the design of aircraft and the design of airports, and also between these two factors and the efforts to achieve all-weather operation. Aviation history will reveal that the airplane was designed first and then the airports were constructed to satisfy the needs of the airplanes as built. As the goal of all-weather operating conditions is approached, electronic equipment that will overcome the deficiencies in both airplane and airport design is an urgent need. Unless a most intimate relationship between the design and construction of our airports, airplanes, and electronic equipments can be established, the cost of providing adequate airports, airplanes, and service can become economically prohibitive.

Somewhere along the line there is an area of diminishing returns, in which the cost of reducing cancellations and interruptions to scheduled operations makes the undertaking no longer profitable. The answer is to be found in the design of aircraft and airports and in the selection and installation of airborne and ground equipments to accomplish all-weather flight. Failure in any one of these fields of development can easily dictate failure of the all-weather objective.

Unless aircraft are designed to fit airports and to overcome certain flight and weather phenomena, and unless airport and equipment costs are kept down and maximum use made of all equipment that can be economically supplied, the over-all cost of providing all-weather operation is greater than the value of the benefits to be derived from such operation.

Note.—Written comments are invited for publication: the last discussion should be submitted by April 1, 1952.

[1] Vice Pres., Operations and Eng., Air Transport Association of America.

All-Weather Operation

Very definite progress has been made since 1946 in reducing cancellations and delays and improving flight regularity. In 1946, the scheduled airlines sustained a loss of revenue due to delays and cancellations of more than $40,000,000. In 1947, this loss was even greater due to the disastrous winter of 1946–1947 that so disrupted public confidence in the airplane as a medium of travel that load factors dropped to an all-time low. A conservative estimate places the 1947 loss at an excess of $50,000,000. In 1948, a number of new electronic aids and certain operational improvements reduced the loss to $32,000,000. In 1949, in spite of substantially increased operations and schedules, the number of cancellations and delays was further reduced. The result was a loss of revenue estimated at $30,000,000. The total expenditure over the period 1946–1950 for improved terminal navigational aids necessary to bring about this reduction is something less than $20,000,000. The most important reason for this reduction in revenue losses is that the aids installed on the ground and in airplanes have permitted lowering of landing and operating minima from 400 ft of ceiling and 1 mile of visibility to 200 ft of ceiling and ½-mile visibility. This reduction in operating limits eliminated 56.5% of the previously nonflyable weather.

It must be readily apparent that progress since 1946 has paid a very handsome return on the capital investment; and this progress has been realized without any really significant change in the concept of aircraft or airport design. Progressive reductions in minimum operating limits will probably go through at least three stages: (1) A reduction 200 ft of ceiling and ½-mile visibility to 100 ft and ¼ mile; (2) a further reduction to 50 ft and ⅛ mile; and (3) finally from there to an all-weather operation. There could be an intermediate stage involving a reduction from 50 ft of ceiling and ⅛-mile visibility to a zero ceiling and $\frac{1}{16}$-mile visibility.

As these progressive reductions are made, each stage eliminates less unflyable weather, yet costs more. It will also be found that if this cost is to be kept to a minimum, some change will be required in aircraft and airport design, and that there must be a close liaison in aircraft, airport, and electronic design and planning.

By way of illustration, as previously stated, the first reduction from 400 ft of ceiling to 200 ft eliminates 56.5% of the nonflyable weather. At 11 major terminals in the so-called weather areas of the United States, visibilities of ⅛ mile or less have been recorded as occurring only about 0.5% of the time. Although no figures are available for visibilities of $\frac{1}{16}$ of a mile or less, such extreme conditions are relatively rare—probably occurring no more than 0.1% of the time. Obviously, the number of cancellations and interruptions to service occurring as a result of visibility conditions below ⅛ of a mile will be small by comparison to those that would occur in the range between ⅛ and ½ of a mile.

The question, then, can and undoubtedly will be raised—is the attainment of the all-weather goal a profitable one? The answer is probably an affirmative one, but it is dependent upon careful planning in the field of aircraft and airport design and in the field of electronics and visual aids.

Installation of Equipment

It is possible to define the equipment necessary to achieve all-weather flight and to show the method of accomplishing this goal. As much as $50,000 can be spent per aircraft and $2,000,000 per runway for equipment to meet the anticipated standards for scheduled airline operations to be established by the airlines and the Civil Aeronautics Administration (CAA). Such an expenditure is certainly prohibitive and will undoubtedly prove unnecessary. This point can be developed, however, as an illustration of one path, and an unproductive one, that can be followed, but which, if followed, would dictate the necessity for a change in concept in aircraft and airport design and planning.

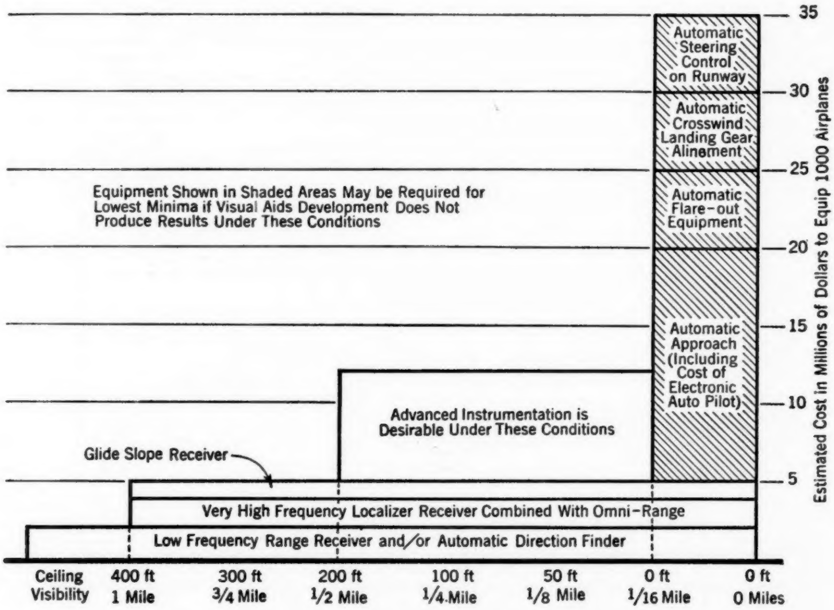

Fig. 1.—Cost of Airborne Equipment with Maximum Use of Visual Aids

Airborne Equipment.—First consider the airplane aspects of the cost of all-weather operations. Figs. 1 and 2 show the distribution of costs for equipment. The costs given do not include maintenance, which will be considerable, nor do they include the cost of carrying the heavy equipment that would be required for all-weather operation. This latter may become a considerable factor when it is realized that it costs an average of $6,250 to transport 100 lb of equipment in one airline aricraft for 1 year (1950).

To equip an entire airline fleet of approximately 1,000 aircraft for 100% all-weather operation would cost approximately $35,000,000. Since most aircraft equipment is amortized on a 5-year basis, this means that this cost would recur every 5 years or, on a prorated basis, is equal to a recurring yearly expense of $7,000,000 for airborne equipment alone. Thus, to do the job by

automatic electronic means alone the cost would appear to be unreasonable. It is unknown with any reasonable degree of certainty whether such equipment as the automatic approach, the automatic flare-out, the automatic cross-wind gear alinement, and the automatic steering control on the runway will be a requirement for a zero operating condition. There is a real basis, however, for a determination of airborne equipment requirements and airplane design for operation down to $\frac{1}{16}$ of a mile. A combination of visual ground aids and simpler airborne equipment will certainly permit operation down to $\frac{1}{16}$ of a mile and perhaps to zero. Such a plan entails a cost for airborne equipment amounting to about $15,000 per aircraft (1950), and fleet costs for 1,000 airplanes would be reduced from $35,000,000 to $15,000,000—a difference of

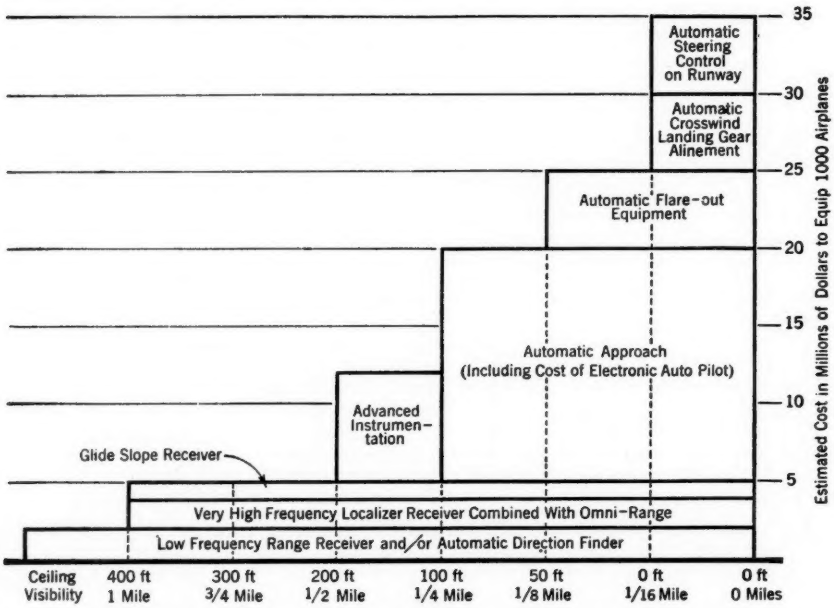

Fig. 2.—Cost of Airborne Equipment Using Electronic Devices

$20,000,000—repeatable each 5 years. This computation certainly dictates a careful analysis and evaluation of the over-all costs for all-weather operation. Such an analysis can be made only by starting at the airport.

Ground Equipment.—The airport problem must be considered in two phases: (1) The equipment requirements to properly implement a runway for instrument operations and the cost of such implementation; and (2) a consideration of the airport layout and design. The two are related and when combined are certainly related to airplane design.

Equipping a single runway for all-weather operation will cost a minimum of $350,000 (1950) and may run as high as $1,150,000 if it is found that some Fog Dispersal Unit, such as FIDO is required for operation below $\frac{1}{16}$ of a

mile visibility (see Fig. 3). This is mentioned because it is very doubtful if, for economic reasons alone, more than 1 or 2 runways will be equipped for complete instrument operations. Regardless of the economics of the question, such factors as the proximity of other airports, terrain obstructions, other flight patterns, and the like make it operationally improbable that more than 2 runways would be used during instrument operations.

Airport Requirements

Airports have become extremely expensive facilities. As progress has been made in the field of aircraft design, increased weight and speed of aircraft have imposed stringent airport requirements that show up to a marked degree in the cost and size of the terminals. As the weight, speed, and wing-loadings of the aircraft have increased, larger terminals and longer runways have been

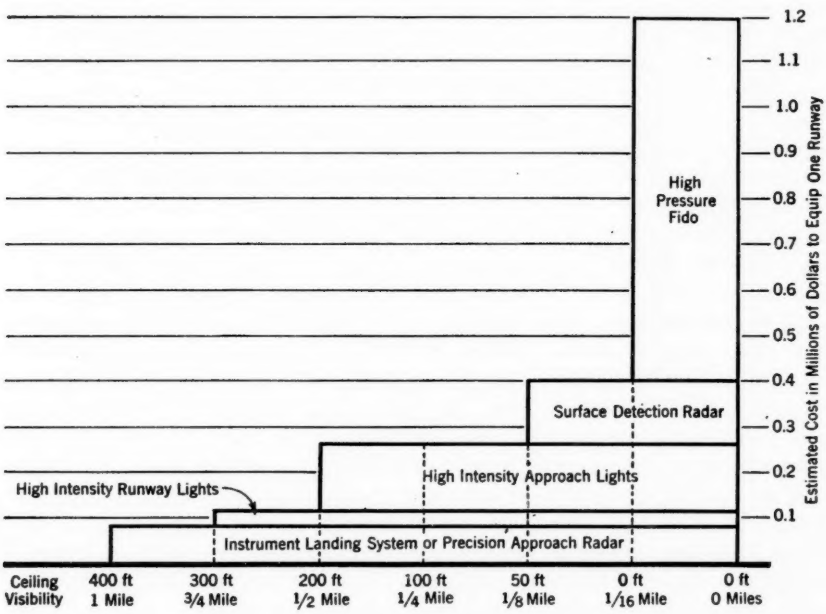

Fig. 3.—Cost of Ground Equipment

required. As greater land areas were required, it has been necessary to move the airports farther from the centers of the municipalities that the airport was intended to serve.

Here again is found an area of diminishing returns. Land areas of such dimensions are required that necessary expansion and land acquisition is possible only in outlying areas. Aviation is unlikely to attract a passenger when the ground time to reach an airplane from the downtown area equals or exceeds the time required to conduct the flight. Obviously, the longer the flight, the further the airport may be from centers of population. The great

untapped market of commerical aviation, however, lies in the short-haul field of 1,000 miles or less. Hence, airports must be kept within a reasonable distance of the downtown area, and such a requirement dictates a change in the design of our aircraft. As long as our concept of airports embodies a multi-runway pattern, the realization of this requirement becomes more and more remote.

Our commercial airports today are monstrosities from the standpoint of size and area. The cost of a single runway designed in 1950 to support aircraft the size of a Boeing 377 almost equals the cost of a complete airport in 1935. Such a runway costs approximately $10.50 per sq yd or $1,500,000. A medium heavy aircraft, such as the DC-6 and the Constellation, requires a runway costing on the order of $7.50 per sq yd or $750,000 (1950).

When these basic runway costs are multiplied by the number of runways normally comprising the airport and when this sum is added to the cost of implementing parallel runways for 100% all-weather operation, it becomes clearly evident that aircraft and airports must be designed to make maximum use of these expensive facilities.

Aircraft design, airport design and implementation, and all-weather operation must be considered as a basically single problem. Attention should be directed to careful cost analysis and comparison of this analysis with anticipated return from capital investments, like airports and facilities for instrument operation.

Multi-runway airports are built with clear-weather approaches from at least 6 directions. Yet, during instrument weather conditions only 2 of these runways are used—one for landings and one for departures. There are two basic reasons for this. First, other air traffic, obstructions, terrain, and proximity of other airports are the operational limiting factors. Second, the economic factor of equipping even 1 runway for all-weather operation is such that only the larger cities can afford a runway fully equipped with instrument landing system, precision approach radar, high intensity approach and runway lights, surface detection radar, and similar necessary equipments.

The economic and operational limitations that restrict an airport to a parallel or 2-runway operation are not likely to be overcome. It seems fitting, therefore, to direct attention primarily toward making these 2 runways do the job under both instrument and clear weather conditions that the 6 runways do in clear weather. If this can be accomplished, then a tremendous step has been taken toward the reduction of ground or plant costs.

Aircraft Design

The dual objective of lowered ground costs and further inroads into the short-haul travel market can be realized only if there are changes in aircraft design. Some progress has been made in this direction. The tricycle landing gear has increased the allowable cross-wind component, reversible-pitch propellers have increased the allowable down-wind component, and there will be other improvements. But this fact is clear—aircraft design must be oriented in the direction of meeting airport requirements just as in the past the airports have been designed to meet aircraft requirements.

Here, basically, is what is required in aircraft design: (*a*) Cross-wind or caster-gear landing structures must be installed on the airplane; (*b*) slower landing speeds must be achieved, along with shorter take-off runs, and improved braking characteristics; and (*c*) aircraft designed primarily for short-haul operation must be designed capable of operation into smaller airports close-in to the downtown area.

The Parallel Runway Airport

If the conditions of aircraft design are met, then the case for the parallel runway airport becomes more clear. Such an airport is illustrated in Fig. 4. This airport employs the continuous flow principle, and its outstanding features are summarized as follows:

1. There are no crossing intersections;
2. High speed turnoffs are provided to clear the runways;
3. All aircraft move in the same direction on the taxiways;
4. There are equal facilities for both directions of approach;
5. Landing directions may be reversed without disrupting operations;
6. All taxi areas and runways are visible to the tower or ground surveillance radar; and
7. A minimum of taxi distance is required.

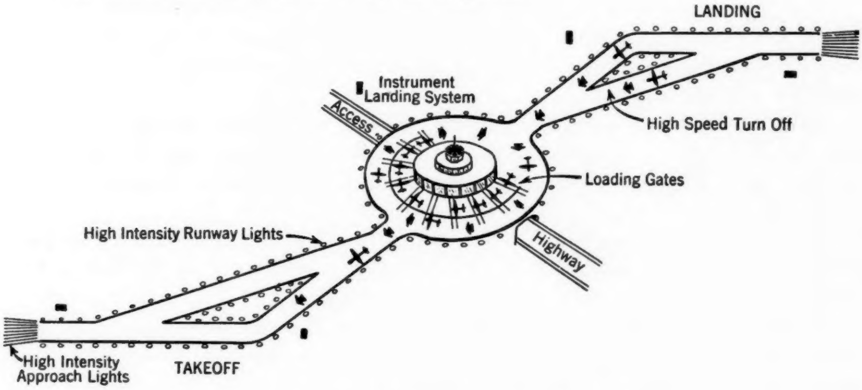

Fig. 4.—Example of Continuous Flow Airport

If the parallel runway airport can be accepted and used, then aviation can afford an all-weather operation. The operational advantages of this type airport are outlined as follows:

a. Regularity of schedules is occasionally dependent upon factors other than weather. Snow removal, for instance, can cause hours of delay. The ability to concentrate on the removal of snow from a single or dual runway could, in many cases, cut delays from this cause.

b. In congested areas, the number of airports that can be used during instrument conditions is dependent to a large extent on the circling radius of aircraft. By polarizing all runways and traffic patterns in such an area, it

should be possible to achieve much closer spacing of airports with no decrease in safety.

c. Simplified traffic patterns resulting from single-axis approaches should go a long way toward unsnarling the traffic problem. Airport surveillance radar could be much more effective under these conditions than with the random picture seen on radar screens today (1950).

d. Airport surface traffic control, which is becoming more and more of a problem as minima are lowered, would be greatly simplified by a much more efficient and simpler taxiway pattern. The airport layout would enable the tower to be placed so that better visibility of the operational area could be achieved.

e. Access to the airport and the location of the airport adjacent to principal highways and population areas would be facilitated. Fully automatic landing does not appear practical until the extremely difficult problem of the drift angle at the touchdown point is overcome. The only technically feasible solution to this problem appears to lie in the use of the caster or cross-wind landing gear, and for this reason this factor has been placed foremost in the aircraft design problem. A parallel runway airport is feasible only if this development is achieved.

Recommendations

Three principal recommendations are made in connection with this subject. All of the following recommendations must be tempered by considering the existing climatic conditions, including the wind rose, as related to ceiling and visibility at each location.

First it is recommended that aircraft design be directed toward operation into parallel runway airports and, in this connection, that the development be intensified in the field of cross-wind landing gears, slower landing speeds, shorter take-off runs, and a short-haul aircraft.

Second, it is recommended that the attention of airport designers and planners be directed toward a simplification of the airport layout and a correlation of this activity with the field of aircraft design.

Finally it is urged that the attention of all be directed toward a closer-knit relationship between aircraft design, airport design, and the development of electronic and visual aids for the common goal of all-weather operation.

If these three conditions are met, then all-weather operation becomes a very feasible goal and will prove to be a profitable undertaking. If they are not met, then that goal becomes a most expensive one, and in all probability will prove to be economically unjustified.

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